(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 February 2003 (27.02.2003)

PCT

(10) International Publication Number
WO 03/017655 A1

(51) International Patent Classification[7]: H04N 5/74, G03B 21/00

(21) International Application Number: PCT/JP02/07919

(22) International Filing Date: 2 August 2002 (02.08.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/930,532 15 August 2001 (15.08.2001) US

(71) Applicant: MITSUBISHI DENKI KABUSHIKI KAISHA [JP/JP]; 2-3, Marunouchi 2-chome, Chiyoda-ku, Tokyo 100-8310 (JP).

(72) Inventor: RASKAR, Ramesh; 61 Clarendon Avenue, #2, Somerville, MA 02144 (US).

(74) Agents: SOGA, Michiharu et al.; S. Soga & Co., 8th Floor, Kokusai Building, 1-1, Marunouchi 3-chome, Chiyoda-ku, Tokyo 100-0005 (JP).

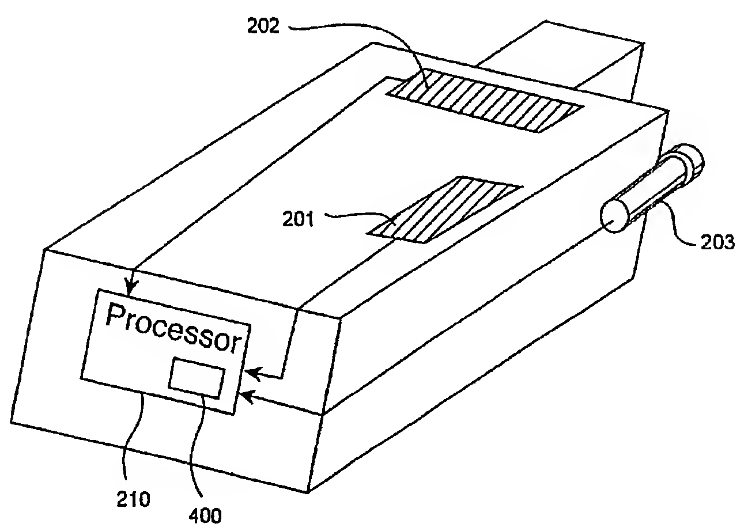
(81) Designated States *(national)*: CN, JP.

(84) Designated States *(regional)*: European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR).

Declaration under Rule 4.17:
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations*

Published:
— *with international search report*

(54) Title: METHOD AND SYSTEM FOR CORRECTING KEYSTONING IN A PROJECTOR ARBITRARILY ORIENTED WITH RESPECT TO A DISPLAY SURFACE



(57) Abstract: A method corrects keystoning in a projector arbitrarily oriented with respect to a display surface. An elevation angle, a roll angle, and an azimuth angle of an optical axis of the projector are measured with respect to the display surface. A planar projective transformation matrix is determined from the elevation, roll, and azimuth angles. A source image to be projected by the projector is warped according to the planar projective transformation, and then projected onto the display surface.

WO 03/017655 A1

DESCRIPTION

METHOD AND SYSTEM FOR CORRECTING KEYSTONING IN A PROJECTOR ARBITRARILY ORIENTED WITH RESPECT TO A DISPLAY SURFACE

Technical Field

This invention relates generally to image projectors, and more particularly, to correcting keystoning problems in projected images.

Background Art

Portable digital image projectors are common. These projectors, while connected to a PC or VCR, sit on a table and are aimed at a projection surface to show a "slide" presentation or a video. Many of these projectors use transmission LCDs, and typically only have a single main lens. The projectors can display images one at the time or as a sequence of images.

These projectors are typically designed so that level undistorted images are projected on the projection surface when the projector is placed horizontally on a level support surface, so that the projector's optical axis is lined up perpendicular to the, typically, vertical projection surface. If any of the above assumptions is violated, then the resulting image on the projection surface may not be rectangular and will be, at best, a trapezoid, and at worst an arbitrary quadrilateral. This

problem is called keystoning.

With prior art projectors, the only way to correct keystoning is to tediously adjust the physical position of the projector by moving it around, tilting and rotating it, until a near rectangular image is displayed. In some cases, it may be impossible to physically adjust the position of the projector. For example, the projector may need to be well above or below the display surface. Some prior art projectors correct the distorted image optically or by the user providing projector positional data.

U.S. Patent No. 5,548,357, "Keystoning and focus correction for an overhead projector," issued to Appel et. al. on Aug. 18 1998, describes a system where a test slide is displayed. A user identifies line pairs most parallel to each other. The line pair identification activates a distortion correction program that uses the oblique angle between the horizontal plane through the projector and the viewing screen.

U.S. Patent No. 5,795,046, "Method for pre-compensating an asymmetrical picture in a projection system for displaying a picture," issued to Woo on Aug. 1998, describes a system where the projection angle, and the trapezoidal error, is compensated for by the user entering in positional information into the system via a keyboard.

Disclosure of Invention

A method corrects keystoning in a projector arbitrarily oriented with respect to a display surface. An elevation angle, a roll angle, and an azimuth angle of an optical axis of the projector are measured with respect to the display surface.

A planar projective transformation matrix is determined from the elevation, roll, and azimuth angles. A source image to be projected by the projector is warped according to the planar projective transformation, and then projected onto the display surface.

Brief Description of Drawings

Figure 1a is a illustration of a projector oriented perpendicularly to a planar display surface;

Figure 1b is a illustration of a projector oriented obliquely to the planar display surface;

Figure 2 is a illustration of a projector according to the invention;

Figures 3a-c illustrate three rotational angles associated with projectors;

Figure 4 is a flow diagram of a warping function used by the invention. 4 is a schematic illustration of the image synthesis of the display system.

Best Mode for Carrying Out the Invention

Figure 1a show a projector 100 placed on a table 10 and oriented at a display surface 101 so that a projected image 102 is perfectly rectangular. This requires that the optical axis of the projector 100 be perfectly aligned perpendicularly to the plane of the display surface 101, and that there is no rotation about the optical axis.

Figure 1b shows a projector 103 placed obliquely on the table 10 and aimed at the display surface 101. In this case, a projected image 104 is some arbitrary shaped quadrilateral due to the oblique angle between the optical axis and the display surface.

The present invention describes a method and system to correct the distorted image 104 to the required rectangular shape 102 as seen in Figure 1. As a result, this allows a user to casually place a projector on a surface, without being concerned if the table top is perfectly horizontal, and the projectors optical axis is perfect perpendicular to the display surface.

As shown in Figures 3a-3b, when the projector is placed obliquely, or the table is titled, or the floor is tilted, or any combinations of these, the obliqueness can be expressed in terms of the three angles, elevation 301, roll 303, and azimuth 305. Each angle is a measurement between the actual angle of

the optical axis 311 and the ideal angle 312 of the optical axis, i.e., perpendicular to the display surface and no rotation. In the ideal setup, as shown in Figure 1, all the three angles are zero.

In the present invention, the values of these three angles 301-303 are determined automatically using sensors mounted on the projector 200 as shown in Figure 2. Figure 2 shows the projector 200 according to the invention. The projector 200 includes multiple sensors, e.g., tilt sensor 201-202, and a camera 203. The sensors 201-202 can also be accelerometer implemented using 2D-accelerometer boards, for example, the ADXL-202 from Analog Devices, Inc. The camera 203 can be any digital camera with digital out-put signals. The camera 203 acquires an input image of a registration image having a predetermined pattern, e.g., a checkerboard pattern. These are well known.

It should be noted that the angles 301-303 shown in Figure 3 can be sensed by other techniques such as lasers, magnetic sensors, or gyro sensors. With fewer sensors, e.g. , one or two, some keystoning effects can be compensated. For example, a single sensor can correct for a non-zero elevation angle 301.

The sensors 201-203 are coupled to a processor 210. The processor 210 is conventional in terms of its hardware and operating system software. Application software implements the

method 211 according to the invention. The method 4001 warps images, before they are projected, according to measurements taken by the sensors 201-203. The warping causes the otherwise arbitrary quadrilateral 104 to be projected appear as a rectangle.

The elevation angle 301 and the roll angle 320 are independent of the geometric relationship between the projector 200 and the display surface 101. Hence, these two angles can be sensed or measured using tilt or gravity sensors. For example, the sensor 201 is placed parallel to the optical axis of the projector, and the sensor 202 that measures the roll angle 302 around the optical axis it is placed perpendicular to the optical axis of the projector. The azimuth angle 303 is determined by viewing a projected image with the camera 203.

The azimuth angle 303 is derived from a single planar projective transformation (homography) between pixel locations in the projected image and corresponding pixel locations in an input image acquired by the camera 203 of the projected image, described in greater detail below.

Figure 4 shows the steps of the warping 400 according to the invention. Typically, the computer application 211 generates a rectangular image 400, having corners generally marked A, B, C, and D. The method 400 determines a suitable

quadrilateral 401, which when projected onto the display surface 1091, appears as a *correct* displayed image 402, i.e., the image is rectangular and axis aligned with the real world sense of what is horizontal and vertical.

The warping 400 scan converts the image 400 into the quadrilateral (warped) image 401 using the homography determined from the sensor measurements. The warping can be performed by texture mapping or image warping such as is available in conventional rendering engines. The homography is defined by the three angles 301-303. The warped image 401 is the input for the obliquely positioned projector 200 according to the invention. The correct displayed image 402 is an axis aligned rectangle that fits inside the quadrilateral 104. In the shown example, the axes are horizontal and vertical directions.

Rendering Process Given Three Angles using 3D Graphics

The elevation and roll angles 301-302 are determined directly from the sensor 201-202. The azimuth angle 303 is determined by the following steps. Using the calibrated camera-projector pair, find the location of features in the input image acquired by the camera 203 of the registration image, e.g., corners or lines of the checkerboard pattern. The features are located in 3D in projector coordinate system. The projector coordinate system has a center of projection at the optical center

of the projector, and an optical axis along the positive z-axis of the projector coordinate system.

The equation of a plane passing through at least three features is determined. The normal of this plane is N = [Nx, Ny, Nz]. A projection in the x-y plane is N_{xy} = [Nx, Ny, 0]. The dot product of a normalized N_{xy} and projector optical axis [0 0 1] is the cosine of the azimuth angle = $\cos^{-1}(N_{xy} \cdot [0\ 0\ 1])$. After the three angles are determined, there are a number of ways of warping and rendering a correct image. Here, is a preferred method.

The projector illuminates an image with width *W* and height *H* at a distance *D* from the projector. This situation can be represented by a 3D coordinate system with the projector is at the origin and the illuminated rectangle on the display surface 101 is parallel to the x-y plane at z = D.

The extents of the projected quadrilateral are [W_{Left}, W_{Right}] along x-dimension, and [H_{Bottom}, H_{Top}] along the y-dimension, $W = |W_{Right} - W_{Left}|$ and $H = |H_{Top} - H_{Bottom}|$. This type of projection cone can be represented by a 3x3 perspective projection matrix P indicating the internal parameters of the projector that define the focal length and image center.

The three angles elevation, roll, and azimuth correspond

to three 3x3 rotation matrices R_e, R_r, R_a. The goal is to render the source image texture mapped on a rectangle of size W x H. The rectangle is axis aligned in the x-y plane, and centered at the origin. The image is calculated from a rendering camera, with parameters P and the transformation defined below. This will give the required warping effect. A point [X, Y, 0] on the rectangle in x-yplane is mapped to a pixel [x,y] with the following transformation and projection equation:

$[x \;\; y \;\; 1] \sim= P * [\, (R_r * R_e * R_a * [X \;\; Y \;\; 0]^T) + [xs,\;\; ys,\;\; D]^T,$

where $xs = (W_{Left} + W_{Right})/2$, and $ys = (H_{Bottom} + H_{Top})/2$.

A second method achieves the same effect by warping the source image with a 3x3 homography matrix H between the corresponding set of points {m} and {n}.

If

$[nx \;\; ny \;\; 1]^T \sim= P * [\, (R_r * R_e * R_a * ([(mx - xs) \;\; (my - ys) \;\; 0]^T) + [xs,\;\; ys,\;\; D]^T \;),$

then the homography H is given by

$[nx \;\; ny \;\; 1]^T \sim= H * [mx \;\; my \;\; 0]^T.$

Four or more pairs of {m = (mx, my)} and {n = (nx, ny)} are sufficient to determine the homography matrix H. A good set of choices for candidate {m} used in homography computation are the corners of the image rectangle WxH.

The invention effectively enables casual placement of a projector to generate correct imagery without distortion eliminating expensive electro-mechanical adjustments. The invention makes it possible to install a projector in any orientation e.g. upside down or resting on its side, and detect the parameters of correct imagery by adding sensors along various directions.

This invention is described using specific terms and examples. It is to be understood that various other adaptations and modifications may be made within the spirit and scope of the invention. Therefore, it is the object of the appended claims to cover all such variations and modifications as come within the true spirit and scope of the invention.

CLAIMS

1. A method for correcting keystoning in a projector arbitrarily oriented with respect to a display surface, comprising;

measuring an elevation angle, a roll angle, and an azimuth angle of an optical axis of the projector with respect to the display surface;

determining a planar projective transformation matrix from the elevation, roll, and azimuth angles;

warping a source image to be projected by the projector according to the planar projective transformation; and

projecting the warped source image onto the display surface.

2. The method of claim 1 wherein the elevation and roll angels are measured by tilt sensors, and the azimuth angle is a camera coupled to the projector.

3. The method of claim 2, further comprising:
acquiring an input image of a registration image; and
determining the azimuth angle from the input image.

4. The method of claim 1 further comprising:
measuring the elevation angle with a tilt sensor.

5. The method of claim 1 further comprising:

measuring the roll angle with a tilt sensor.

6. The method of claim 1 further comprising:

measuring the azimuth angle with a camera-projector pair.

7. The method of claim 1 wherein the projector uses a laser beam.

8. A system for correcting keystoning in a projector arbitrarily oriented with respect to a display surface, comprising;

a first tilt sensor measuring an elevation angle of an optical axis of the projector with respect to the display surface;

a second tilt sensor measuring an roll angle of an optical axis of the projector with respect to the display surface;

a camera coupled to the projector measuring an azimuth angle of an optical axis of the projector with respect to the display surface;

means for determining a planar projective transformation matrix from the elevation, roll, and azimuth angles; and

means for warping a source image to be projected by the projector according to the planar projective transformation and projecting the warped source image onto the display surface with

the projector.

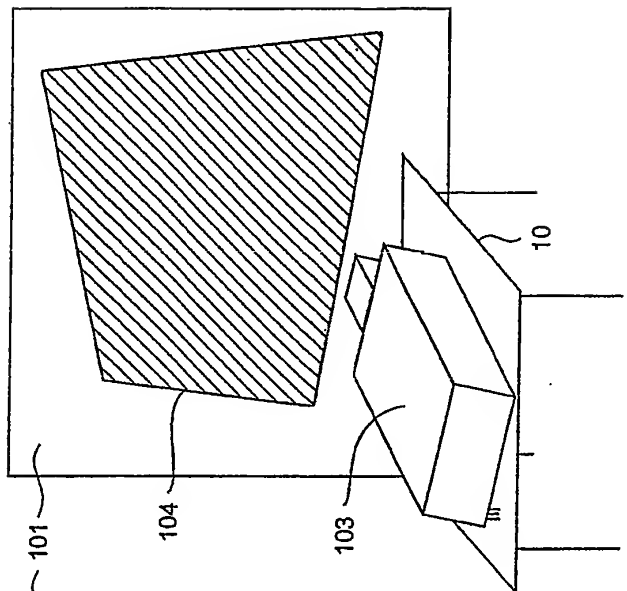


FIG. 1b

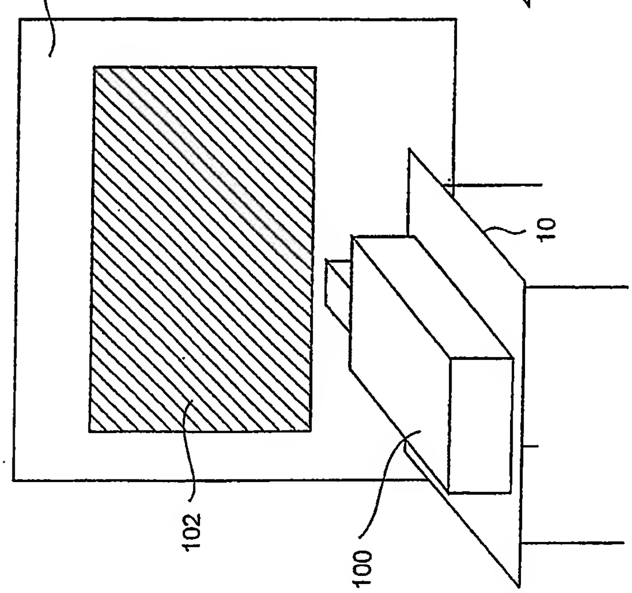


FIG. 1a

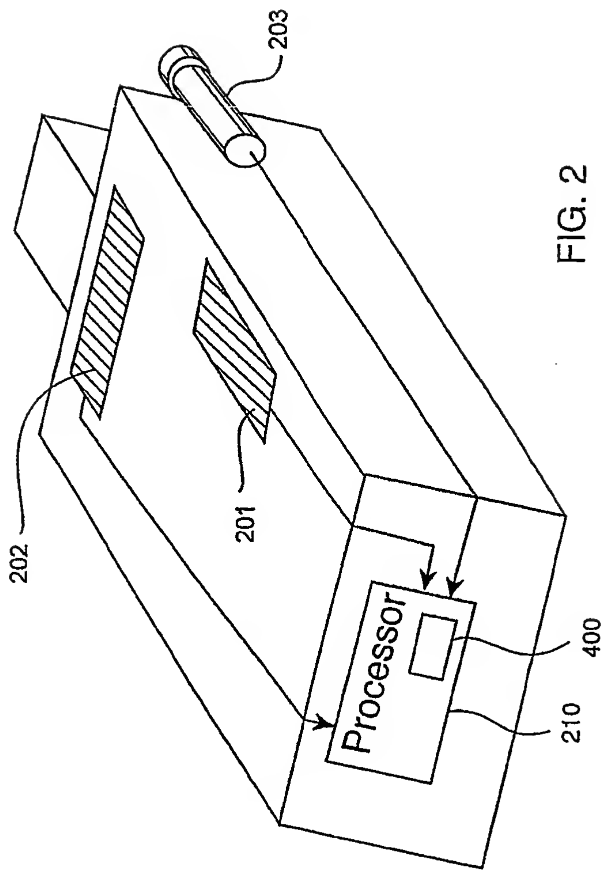


FIG. 2

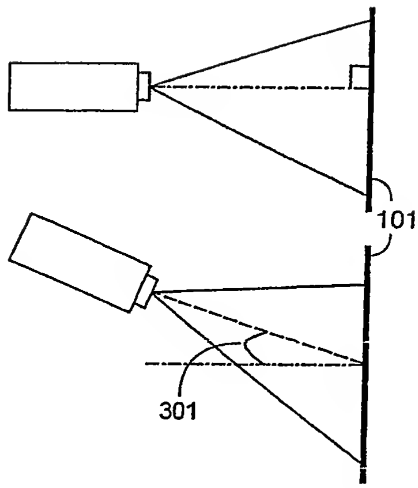


FIG. 3a

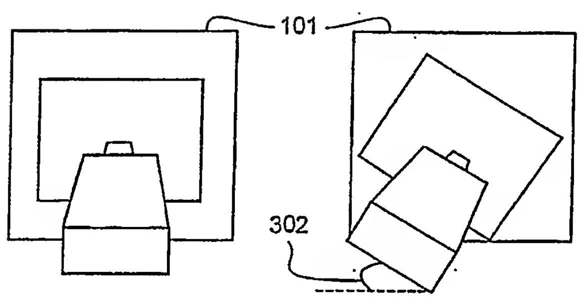


FIG. 3b

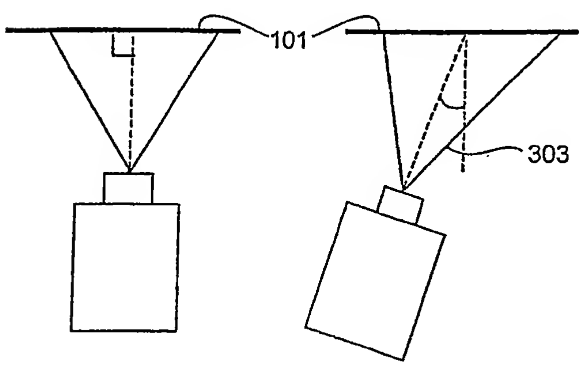


FIG. 3c

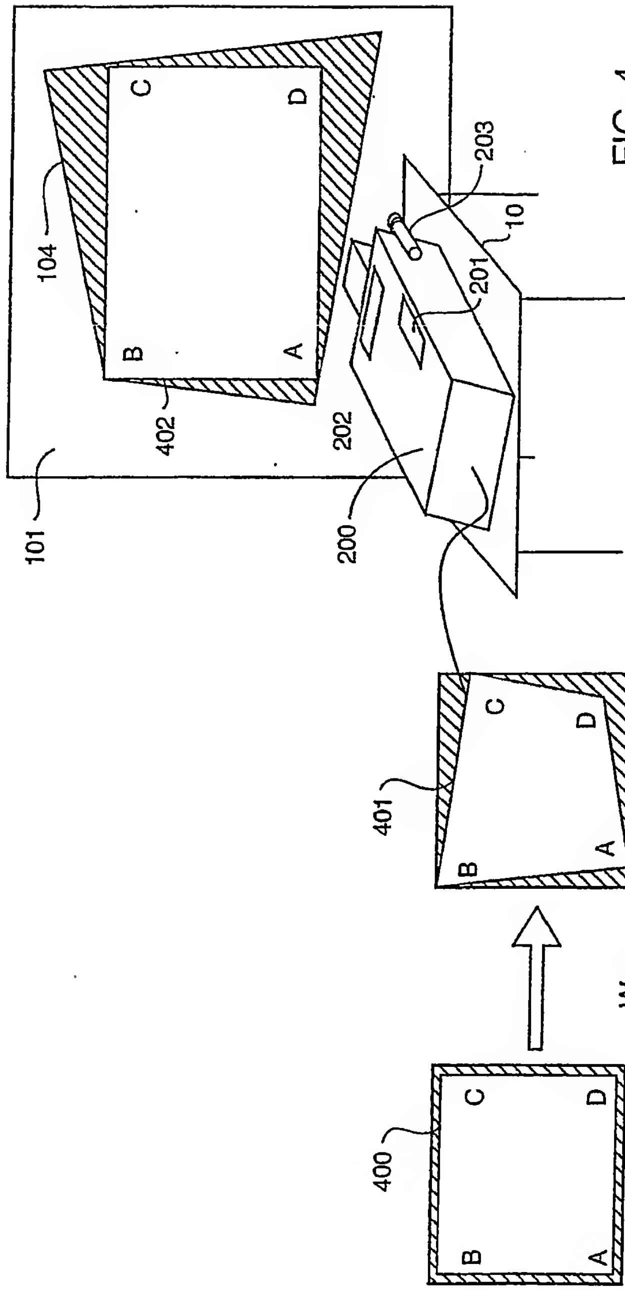


FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/JP 02/07919

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04N5/74 G03B21/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04N G03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 01 47259 A (JUSTSYSTEM CORP ;MULLIN MATTHEW (US); STOCKTON ROBERT (US); SUKTHA) 28 June 2001 (2001-06-28) page 2, line 13 - line 30 page 3, line 13 -page 6, line 2; figures 1-4 ---	1-3,6,8
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 07, 29 September 2000 (2000-09-29) & JP 2000 122617 A (TOSHIBA CORP;TOSHIBA AVE CO LTD), 28 April 2000 (2000-04-28) abstract --- -/--	1,8

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 October 2002	24/10/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Fuchs, P

INTERNATIONAL SEARCH REPORT

International Application No
PCT/JP 02/07919

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 24, 11 May 2001 (2001-05-11) & JP 2001 186538 A (TOSHIBA CORP), 6 July 2001 (2001-07-06) abstract ---	1,8
A	EP 0 756 425 A (DAE WOO ELECTRONICS CO LTD) 29 January 1997 (1997-01-29) abstract column 5, line 57 -column 9, line 44; figures 7-10 ---	1,7,8
A	PATENT ABSTRACTS OF JAPAN vol. 1997, no. 01, 31 January 1997 (1997-01-31) & JP 08 251522 A (FUJITSU GENERAL LTD), 27 September 1996 (1996-09-27) abstract -----	1,2,4,5, 8

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/JP 02/07919

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
WO 0147259	A	28-06-2001	AU	3265401 A	03-07-2001
			WO	0147259 A1	28-06-2001
JP 2000122617	A	28-04-2000	NONE		
JP 2001186538	A	06-07-2001	NONE		
EP 0756425	A	29-01-1997	KR	173704 B1	20-03-1999
			AU	706332 B2	17-06-1999
			AU	6532596 A	26-02-1997
			BR	9606541 A	28-07-1998
			CA	2200863 A1	13-02-1997
			CN	1169228 A	31-12-1997
			CZ	9700836 A3	16-07-1997
			EP	0756425 A2	29-01-1997
			HU	9801147 A2	28-08-1998
			JP	10507332 T	14-07-1998
			WO	9704634 A2	13-02-1997
			PL	319435 A1	04-08-1997
			RU	2151416 C1	20-06-2000
			US	5664858 A	09-09-1997
JP 08251522 8	A		NONE		